Electrostatic Forces

The space around any charged object or particle that can cause a force to act on another charged object or particle is called its *electric field*. This field will cause a force of attraction or repulsion to act on another charged object.

Any point charge will exert an electrostatic force that depends on three factors:
- the size of its charge, in Coulombs (C).
- the size of charge of another object that is being attracted or repelled by the first object.
- the distance between the two charges; the further the distance, the weaker the force of attraction or repulsion.

From this, the size of the force between point charges is expressed as follows, and is known as Coulomb's Law:

$$\mathbf{F = k\frac{qQ}{R^2}}$$

The units in this equation:
- **R** is the distance between the two centers of charge
- **Q** and **q** are the magnitude of each charge, measured in Coulombs
- **k** is the constant of proportionality; i.e.; $\mathbf{k = 9.0 \times 10^9\ N\text{-}m^2/C^2}$

Note that the smallest unit of charge is called the *elementary* charge, represented by the charge of either an electron or a proton. Charge is measured in Coulombs, where one Coulomb = 6.24×10^{18} electrons. Therefore the coulomb charge on one electron or proton is the reciprocal of this number, or

$$\mathbf{1e^- \text{ or } 1p^+ = \pm 1.6 \times 10^{-19}\ C} \qquad \text{(sign depends on charge)}$$

Note that because the coulomb is such a large unit, charges are often measured in microcoulombs or **µC**.

Example 1. Find the electrostatic force between a +3.0 µC charge and a +8.0 µC charge, 0.25 m apart.

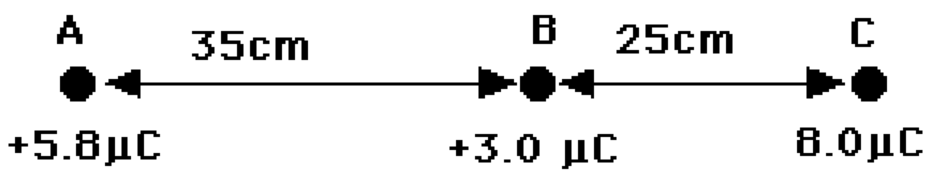
(see Electrostatics Ex 1 for answer)

Example 2. A -6.0 µC charge and a -4.0 µC charge repel each other with a force of 7.0 N. How far apart are these point charges? (18 cm)

(see Electrostatics Ex 2 for answer)

We can use free-body diagrams to examine the relationship between two or more electrostatic forces. That is, if two or more electric forces act on one body the resultant net force is the vector sum of the electrostatic forces.

Example 3. What is the force on the 3.0 µC charge if the charges are positioned along one line as follows.



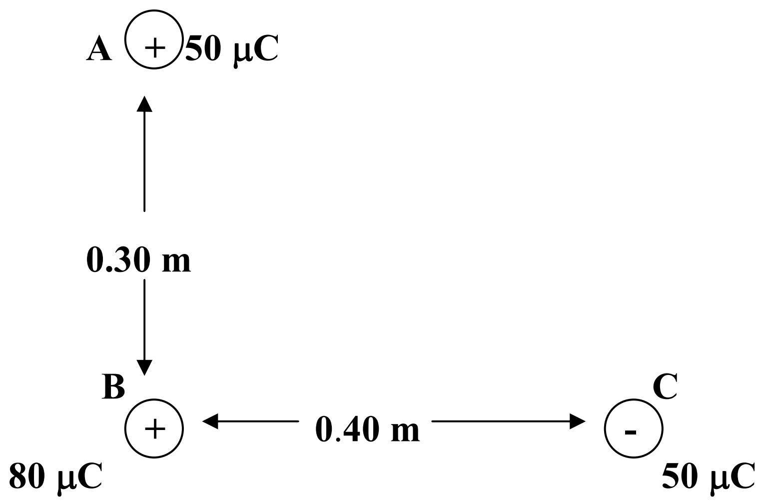
To solve, follow these steps:

- First, draw a free-body diagram of particle **B**, showing the direction of each vector acting on this particle.
- Second, find the magnitude of each electrostatic force ($\mathbf{F_{AB}}$ and $\mathbf{F_{BC}}$) that acts on the charge at **B**. Don't include the sign of the charge in your calculations.
- Finally, vector-add the two forces to find the resultant net force on **B**.

(see Electrostatics Ex 3 for answer)

On the following page is a similar problem, but slightly more difficult. You will need to build a forces triangle and use some trigonometry skills in your last steps to solve.

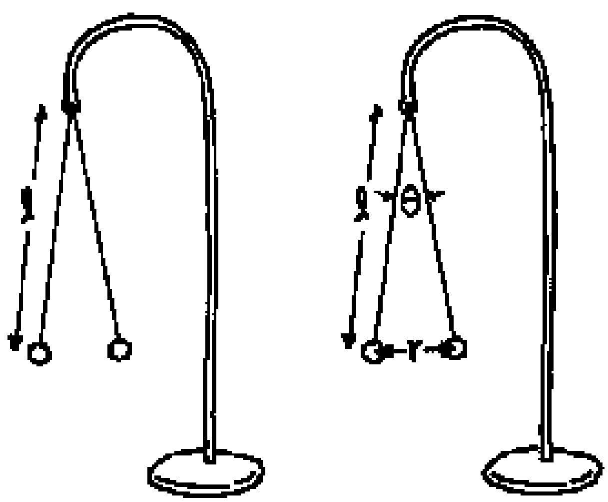
Example 4. Three charges are laid out as in the following diagram. Find the resultant force due to the other two charges on charge B.



(see Electrostatics Ex 4 for answer)

We can also use free-body diagrams to examine the relationship between electrostatic and other forces.

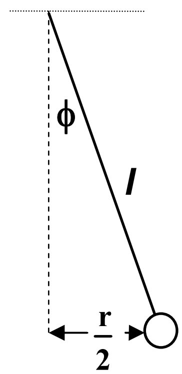
Example 5. Examine the electroscope arrangement below, where two pith balls have identical charges and are repelling each other.



If each string has a length *l* = 0.20 m, the distance of separation between the charged pith balls is r = 0.05 m, and the mass of the balls is 0.010 kg each, find the magnitude of the charge on each pith ball.

Some helpful hints:

- first, find angle ϕ, equal to $\frac{\theta}{2}$:



$$\sin\phi = \frac{2.5}{20} \quad \phi = 7.2°$$

- Next, sketch a f.b. diagram of one of the pith balls and create a forces triangle.
- Finally,from the diagram drawn, equate the electric and gravitational force; this should produce an equation from which charge **q** can be solved (remember that both charges are equal in this question).

(see Electrostatics Ex 5 for answer)

Finally, just like with gravity, the electric force between two charges will change if either of the values for charge changes, or if the distance between the particles changes. And, similar to gravity,

$$\mathbf{F} \propto \mathbf{q} \text{ and } \qquad \mathbf{F} \propto \frac{1}{r^2}$$

For example:

- if either charge **q** doubles, then so does **F**.
- if both charges q_1 and q_2 double, **F** increases by **4x**.
- if distance **r** between the charges doubles, then **F** is reduced to ¼ of the original amount.

Example 6. Two unknown charges have a force between them of 5.6 N. How will that force change if:
a) one of the charges is tripled?
b) one charge is halved and the other quadrupled?
c) the distance between them halved?
d) both charges are doubled and the distance tripled?

(see Electrostatics Ex 6 for answer)